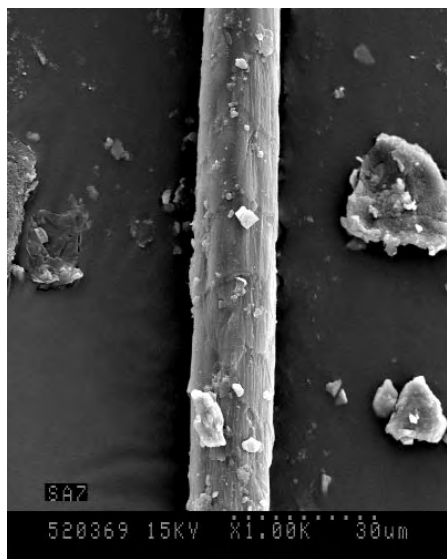




Surface Scanning Electron Microscopy of Suri Alpaca Fiber and Other Members of the Camel Family

By Andy and Dr. Cheryl Tillman



Suri fiber is characterized by an indistinct scale edge that is difficult to visualize even with digital imaging tools.

SEM scanning demonstrates that the cuticular cell length, height, and scale edge angle of suri alpaca fiber is measurably different from huacaya alpaca, cashmere, wool, and other members of the Camel Family.

The Washington State Disease Diagnostic Lab (WADDL) in Pullman, WA analyzed 35 suri alpaca fiber samples with surface scanning electron microscopy in February through November 2005 for the authors. The WADDL normally uses the Electron Microscopy and Imaging Center (EMIC) to identify virus and bacteria species for the state of Washington. Samples were prepared by EM Supervisor Chris Davitt, Ph.D., who took two micrographs of each fiber sample.

To provide a baseline to other members of the Camel Family, 19 llama, eight huacaya, six vicuña, five guanaco, and two de-haired Bactrian camel samples were also analyzed. Other specialty fibers analyzed included one sample each of white angora rabbit, washed fawn mohair, and Bombay silk. Two samples each of Soft Rolling Skin® (SRS) merino wool, and both domestic (in the grease) and very fine, washed white Chinese cashmere were tested.

SEM scanning demonstrates that the cuticular cell scale length, frequency, height, and scale edge angle of suri alpaca fiber is measurably different from these other specialty fibers and other members of the Camel Family. Cuticular scale length is expressed as the Mean Scale Frequency (MSF) per 100 micron (μ) field of view as measured by the SEM. High-luster suri appears to be most similar to cashmere, though it has an even longer and lower scale height. This study has important implications for the alpaca industry, including AOBA and the AFCNA. Suri alpaca breeders can now claim to produce a natural fiber which has luster that is equal to or greater than cashmere. Due to its very low cuticular scale height, both suri and huacaya breeders can explain why their products have superior handle, compared to wool of similar average fiber diameter (AFD).

Terminology

Angstrom (Å): A unit of length, equal to one ten-millionth of a millimeter, primarily used to express electromagnetic wavelengths.

Compound Microscope: An optical microscope with two ocular lenses.

Cuticular Cell Scale: The external-most structure of hair.

Highly Evolved: a merino or huacaya that has a high frequency of crimp, or a suri with unusually high luster or tightly-penciled locks.

Mean Scale Frequency (MSF): The number of cuticle scales per 100 micron that are the mean of the data set.

Micrograph: A digital photograph of the SEM sample.

Micron: 1/1,000,000 of a meter (1/10,000 of a millimeter, or about 1/25,000th of an inch).

Scanning Electron Microscopy (SEM): Use of the electron microscope to view the surface characteristics of an object.

South American Camelid (SAC): A literal translation of Camelidos Sud Americanos, incorporating all the members of the Lama genus, including the alpaca, llama, guanaco, and vicuña.

Transmission Electron Microscopy (TEM): Use of the electron microscope to view an object on-end, rather than on the surface of the subject.

Sample Demographics

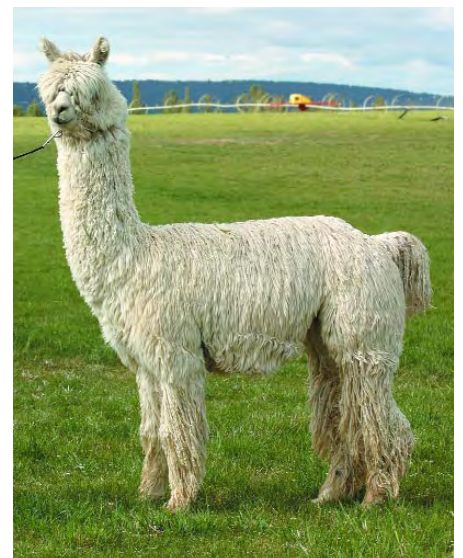
Samples were collected from 35 suri alpacas, comprised of 20 male and 15 females. Thirty of the suris were



Most of the straighter fiber samples had exceptional luster and a low MSF.



The narrow flat lock was highly correlated to luster in this study.



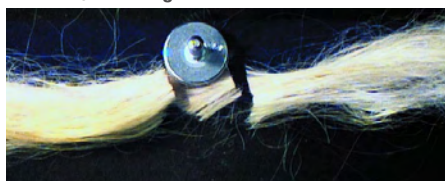
A well-locked suri in his second fleece, like this animal, typically had an MSF of 7-7.5.

offspring from the 1991, 1996, and 1998 Bolivian importations to the USA. These animals were randomly selected from our own herd based on whether we had fiber samples or fleeces saved from the previous year's clip. Three Australian suris were also tested. These were first-generation suris from a suri x huacaya cross that were phenotypically suri. Two more of our suris were from Peruvian origins. Fiber samples were collected in two phases. The first phase of 14 samples was collected from shorn virgin fleeces. The remaining (majority) of samples were taken from unshorn suris using a uniform

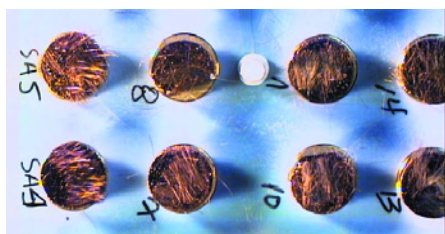
“Yocum-McColl” sample site used for laser scanning. The second phase of fiber samples had a slightly lower MSF than the first. Twenty of the suri alpacas had a uniform age range of 11 to 13 months at the time of sampling. Eight samples from Phase 2 were second or third fleeces, rather than virgin fleeces (and these animals were three to five years old). Three of these could be compared to the same animal's virgin fleece. MSF was within +/- 10% of the virgin fleece. No significant difference was noted between the first and subsequent fleeces. The remaining seven animals were 21 to 25 months old.



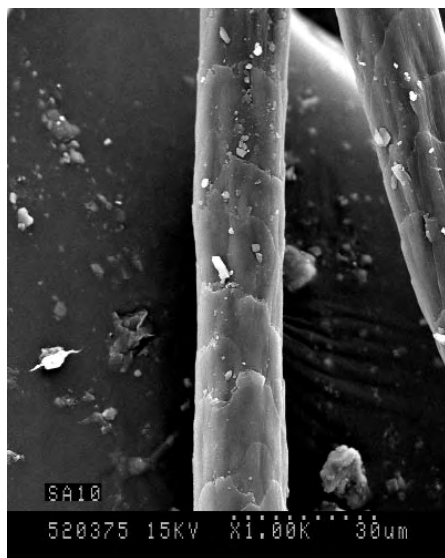
Dr. Chris Davitt, PhD, with sample dishes in front of her Scanning Electron Microscope in Pullman, Washington.



A 13mm long fiber sample is attached to the SEM stub with electrically conductive tape.



The golden fleece! Fiber samples have been coated with 20-30 Å of pure gold prior to being viewed by the Electron Microscope.



The Long Smooth Scale™ of suri fiber can clearly be seen in this micrograph. Average scale length was 16.25µ. The debris in background is dandruff.

According to ARI statistics, over half of all suri alpacas in the United States are colors other than white. About two-thirds of this study were colored: eleven subjects were white, eight brown, seven black, five fawns, three greys, and one beige.

The majority of samples (21) had a twisted style of lock, including several with a highly-evolved “pearl” lock of 3-4 very small inter-twined locks. The style of lock ranged from cotted to “independent.” The remaining samples had either a narrow flat lock (3), a relatively straight fleece that clung closely to the body (6), a fan-shaped lock (3), or a coiled (corkscrew) lock (2). Four of the donors were overweight, and these had the strongest Average Fiber Diameter (AFD). The samples were laser scanned and had an AFD of 16.7-32.8µ with a mean of 22.8µ and 10.3% coarse fibers. All of the subject animals were healthy, de-wormed, body score condition 7-9, and compared to the population at large, free of heat stress (we shear). None of the donors had ever been washed with shampoo or conditioners.

Why SEM?

The SEM micrographs provide detail not obtainable with a conventional compound microscope. An optical microscope uses visible light of a wavelength of several thousand angstroms (Å). Such an instrument is actually a photon microscope, since a ray of light is a beam of photons. An electron microscope uses a beam of electrons instead of a beam of light.

The main advantage of the EM microscope is its potential for very high resolving power. This is based on the possibility of using electrons whose de Broglie wavelengths are less than 1Å. Objects as small as 2.3Å have been resolved, a feat forever beyond the capability of a microscope using visible light.¹

Research Methodology

Micrographs were taken at an accelerating voltage of 15 Kilo Volt (KV) and 1,000 X. The quality of the micrographs taken by a skilled EM instructor like Dr. Davitt made it possible to accurately

measure the length of each scale on a fiber, the height of scale, frequency of scale, angle of scale, and fiber diameter. For the purposes of this article, the relatively simple International Wool Textile Organization (IWTO) DTM-XX-97 methodology was used with the exception of viewing the samples at 1,000 X magnification rather than 600 X. The higher magnification was necessary for accurately measuring suri scale height, which is almost impossible to measure even with digital imaging tools. Wool has a scale height of <8 micron and can easily be measured at 600 X.

Measuring scale height is important, since scale height is one reason suri alpaca fiber has a low coefficient of friction and feels finer than it is.

Following IWTO DTM-XX-97 methodology, the authors counted the number of cuticular scales in a 100 micron field of view. Scale frequency is expressed as a Mean Scale Frequency (MSF). A lower MSF indicates a longer cuticular scale. A higher MSF indicates a series of shorter scales. A literature search revealed that an MSF for wool ranges from 10-12, depending on breed, 6-8 for de-haired cashmere, and 6-7 for de-haired mohair.³ Some care is required to achieve consistent results using IWTO-97 methodology. A variation of 10-30% was possible, depending on where you counted the scales. Wool and huacaya alpaca could easily be counted on the edge of the fiber sample, but suri – which has virtually no scale height – was most easily counted down the center of the fiber. Using Adobe Photoshop to open the micrographs, huacaya scales could be counted viewing the micrograph at 50% actual size, while suri required viewing at 66-200%. We standardized on counting scales on the left edge of the sample viewing it at 100% actual size.

Very precise measurement of fiber diameter, scale length, height, and scale edge angle, can be accomplished using digital imaging software. We tried Scion Corporation’s *Image* for Windows, and *Image-J* software, which is available as a free download by the National Institutes for Health (NIH). The NIH

Image-J was much more stable on our Windows XP platform than the Macintosh-based Scion *Image*, which is an industry standard in SEM labs.

Surface SEM of suri alpacas was first conducted in the United States in 1998 at the University of Idaho at Moscow, by Suvia Judd and Deborah Berman.² Judd and Berman analyzed two fiber samples and hypothesized a high correlation between scale length and luster. SEM of South American Camelid (SAC) fiber has been published at least three times prior to Judd and Berman in 1988 (Phan), 1996 (Antonini *et al*), and 1997 (IWTO). Antonini's study is particularly important. Extracting the data on just Peruvian suris from that of Argentine SAC with "*Lustre*" established that Peruvian suris have a MSF of 7.5. This is equal to cashmere. The 1997 IWTO study of specialty fibers is one of many which have tried to find an economical method of testing large quantities of cashmere for purity. The very low MSF of cashmere, compared to wool, makes SEM an effective tool to identify blended shipments of cashmere.

The author's sample of suri and specialty fibers is the largest domestic analysis conducted to date.

Sample Preparation

Dr. Davitt prepared the fiber sample by cutting the center 13mm (½ inch) out of the locks. Dr. Davitt believed using the center of each sample was preferable to one close to the skin or near the tip, and I concurred. The fiber sample is mounted on an aluminum disc with electrically-conductive tape and screwed into place on the sample dish. A SEM dish holds twelve 13mm sample discs.

The fiber samples were placed in a vacuum chamber and coated with 20-30 angstroms of pure gold. A high voltage is applied in a vacuum chamber to a bar of 99.9% pure gold, which coats the fiber samples with a plasma of gold ions. The SEM is actually visualizing the gold ions that coat the sample, not the fiber sample itself. Platinum and aluminum can also be used to coat the samples.

Commercialization of SEM?

A used SEM costs USD\$50,000. Adding the other peripherals can raise the price to USD \$250,000. Training to prepare the samples and take micrographs would take at least a term of college-level classes in statistics and imaging software. SEM is a powerful tool that can help breeders determine the inherent luster of their most valuable animals. But it is unlikely that SEM will ever be as common a test procedure as laser scanning for determining AFD. The cost of the equipment is just too great. Cuticular scales can be visualized by an inexpensive optical microscope by coating the fiber samples with a lacquer that enhances the contrast of the scales. While sample preparation may be as time-consuming as SEM, this is a much less expensive method of documenting MSF. Unfortunately, the lacquer greatly exaggerates the cuticular scale height of the sample. Since SAC fiber has a very low scale height, SEM is still the preferred method of analyzing surface scale structure.

Luster

Luster is the primary, and probably the only, reason the textile industry purchases suri alpaca fiber.

Suri can be used in many of the same applications as silk and cashmere. It is frequently blended with merino, silk, or cashmere to add luster to the fabric used in men's suits.

*"Luster is strongly associated with mohair, based on its relatively large surface cuticle scales and low cuticle scale edge height relative to merino wool."*³

The end-use of suri alpaca fiber is substantially different than Baby Huacaya, which can compete for fineness with some grades of merino wool. Suri is more likely to be used in a semi-worsted or woolen manufacturing process and huacaya in a worsted yarn like merino. Our study of eight huacaya alpaca samples demonstrated that huacaya breeders can selectively breed for enhanced brightness in their fleece. A reduction in MSF of 25-30% should be relatively easy to accomplish.



A bright fleece like this has a fan-shaped rather than a twisted lock.



Luster is the primary reason the textile industry purchases suri fiber. This brushed suri coat by Beatriz Canedo Patiño is made from 100% suri.



MSF 4.6. Second and third fleeces had a very low MSF. Pictured is a 3 month re-growth on "Rewinds" third fleece. There is no reason not to show shorn suri's in AOBA halter classes!



Twenty-one of the 35 suri samples were from well locked individuals like this. A twisted lock probably does reduce luster compared to a straighter fleece.

Lock

It would be premature to assign value to one lock type over another until a more thorough SEM is made of suri alpaca fiber.

The authors had hoped to identify some correlation between lock types, which naturally occur in the suri alpaca, and the length of scale which is highly correlated to luster. Our sample size was too small to conclusively identify a trend. However, it is probably accurate to say that a straighter fleece is more likely to have a very low MSF than a twisted lock. A literature search suggests that some lock types may actually inhibit perceived luster more than others.

For instance, a high frequency of crimp in cashmere does adversely affect the perceived luster of the fiber.

*"Perceived luster of wool is affected by staple structure and fiber curvature. Low curvature in wool allows the fibers to more closely align. As Khan (1996) reported, if the staple crimp form in wool was 'planar' (sinusoidal as opposed to helical), such wool would have a high luster. On this basis, the use of perceived luster as an aid in the classifying of cashmere may be confounded by different cashmere fiber curvature. Thus luster of cashmere should be assessed on manually straightened fiber to minimize any effect of fiber crimp."*⁴

Applying McGregor's findings to suri alpacas may suggest that a tightly twisted (helical) lock may diffuse light more than a straighter fleece. It may also make the handle feel coarser than it actually is. Analysis of the Baby Camel supports the notion that crimp and/or a twisted lock may reduce luster in SAC fiber.

*"Wool with larger fiber crimp amplitude is associated with softer handle. Wools exhibiting a coiled (helical) crimp configuration receive harsher handle scores than wools with sinusoidal (wavy) crimp configurations."*³

It is probably fair to say that the *de facto* breed standard in AOBA sanctioned shows puts a much greater

emphasis on an "independent lock," than any other characteristic, including luster or conformation. Our SEM study did not identify any correlation between a twisted lock and luster. If anything, they may be inversely proportional. In this study, the relatively straight fleeces, and those with a narrow straight lock usually had a longer and lower scale height than animals with twisted locks. Suri breeders, the AOBA Show Committee, and the Judges Training Committee should keep abreast of SEM technology as it applies to suri alpaca fleeces. It would certainly be premature to favor one lock type over another until the results of TSN 100-fleece study is completed.

Scale Height

The scale height of suri alpaca fiber was almost impossible to measure, even with digital imaging tools. It is essentially a mono-filament, like silk.

The height of scale on suri alpaca fiber was almost impossible to measure, even with digital *Image-J* software. This characteristic is probably as significant to the textile industry as suri's very low MSF. The scale height of both suri and huacaya fiber has not been accurately reported in previous scientific literature, which is probably due to the fact that an optical rather than SEM has been used.

*"The smoothness of alpaca and mohair compared to wool is due to the scales being around half the height of wool at around the same micron."*¹⁰

While Mr. Sporle made an important and accurate observation about the handle of alpaca and mohair, scale height is much lower than "one-half the height of wool." In our study, it was one-tenth the height! Huacaya fiber had slightly taller scale height than suri, but was still typically under 3/10 μ . The most highly evolved Soft Rolling Skin (SRS) merino fiber like that analyzed in this study had a scale height of 3-4 micron, and most merino is <8 micron. Bruce McGregor, in the *Australian Farm Journal 2003*, explained the importance of scale height and length when he wrote:



Compare the lack of scale height of this suri sample to that of merino or cashmere (see photos on p. 168-169).

“The greater the directional friction effect due to the wool fiber cuticle scales, the harsher the handle.”³

This opinion is further enhanced by J.E. Watts and Janie Hicks:

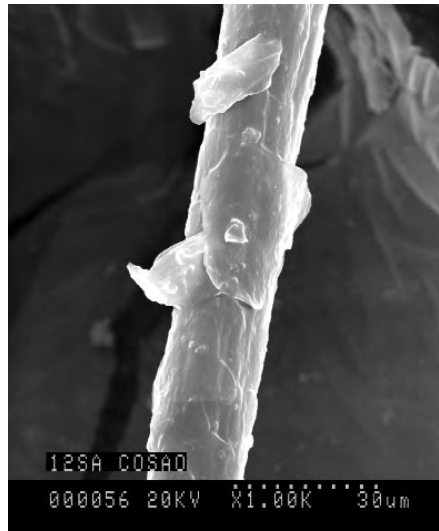
“Fine cylindrical fibers have low scale height. When these fibers are also long, the fiber scales will be long as well as flat. The combination of long flat scales imparts a smooth or silky feel to the wool.”⁵

Because wool has such a high scale height compared to suri, whether an individual fiber is round or elliptical is probably not as important to alpaca breeders as it is to merino producers.

Round or Elliptical Fibers?

While Watts’ and Hicks’ SRS system is not universally accepted, their research strongly suggests a correlation between handle and a round rather than elliptical fiber. When I showed these SEM micrographs to Ian Watt, he soon found fibers that he believed were elliptical rather than round. These are easily identified by two thin grooves running parallel to the direction of the fiber with a rounded segment between them.

About a third of suri and huacaya samples had one or two grooves running the entire length of the fiber. Most were completely round. No llama, guanaco or camel samples



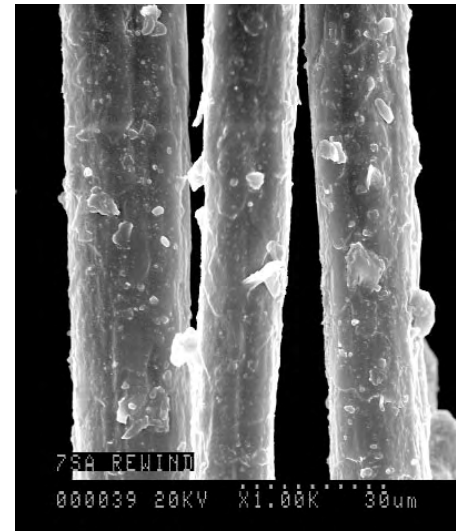
The low scale height of suri can clearly be seen in this micrograph which shows three damaged cuticle scales. Notice how thin they are!

appeared to be elliptical. One vicuna had distinct grooves. Since there were frequently two fibers in each micrograph, and occasionally three, we analyzed nearly 200 suri and huacaya fibers for roundness. The elliptical samples tended to come from suris that were well locked, but not exclusively so. More research will be needed to determine what, if anything, this difference in fiber profile means. TEM and/or skin biopsies would be a more accurate way to determine if a hair follicle is round or elliptical.

To an end-user, the very low scale height of suri is probably of much more significance than if an individual fiber is round or elliptical. You can appreciate this for yourself by feeling the “hand” of a neck scarf made from pashmina (cashmere) or merino wool of similar AFD.

Transmission Electron Microscopy (TEM)

TEM can also be used to visualize the cortex of a fiber sample. The percentage of orthocortical and paracortical cells in the cortex is important. Wool is bilateral, with both orthocortical and paracortical cells, which is responsible for its crimp.⁹ Cashmere with more mesocortical cells, has a higher microfibril packing density than wool of the same diameter, so it has less curvature. Optical analysis of suri fiber



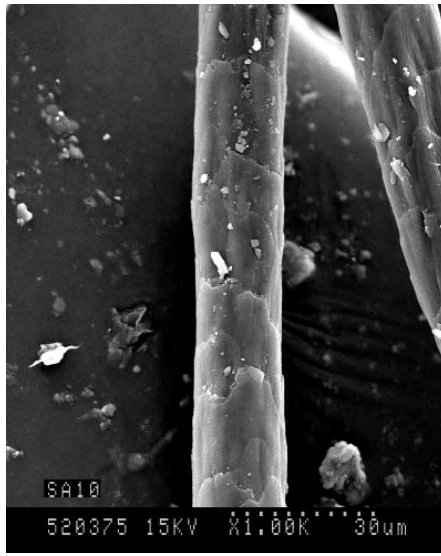
The scale edge of suri is so indistinct that it was difficult to measure even with digital imaging tools.



Elliptical Suri Fiber – MSF 5.25. About 30% of the alpaca samples had one or two grooves running along the surface of the fiber, indicating they are probably elliptical rather than round.



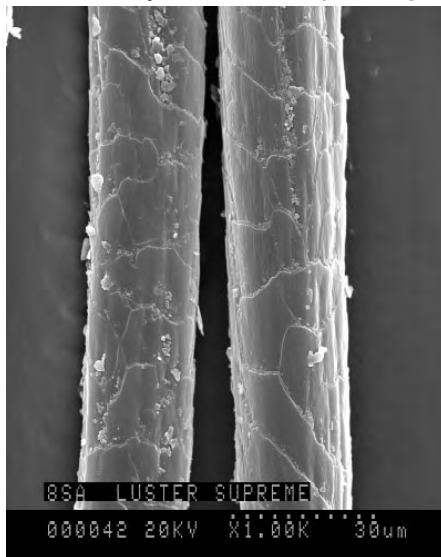
MSF 5.0 Suri is nearly as bright as mohair but has a much lower AFD.



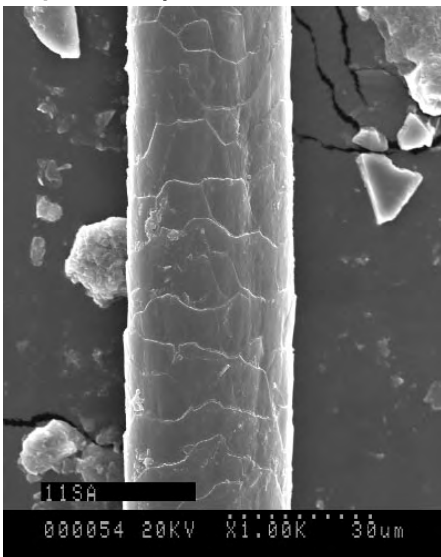
MSF 5.75. Suri breeders need to reduce the AFD of their clip to be competitive with other specialty fibers. This sample is both fine (<19µ) and bright.



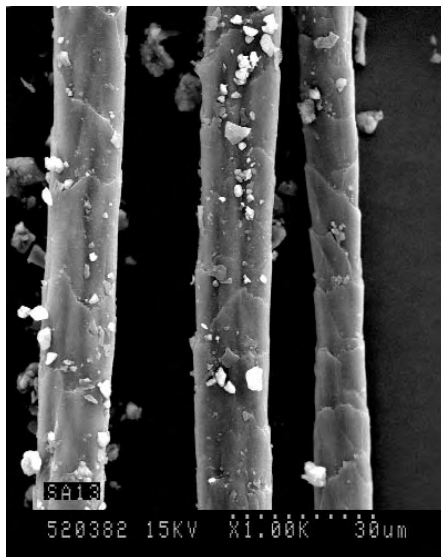
MSF 6.5. The MSF of suri alpaca fiber in the study of 35 suri alpacas was 6.15/100 micron.



MSF 7.0. The suri sample in this image has a lower MSF than cashmere.



MSF 10.0. The highest frequency suri had a lower MSF than the mean of all huacaya samples.



The finest suri analyzed may be showing signs of a "wool break" on the far right. AFD was just 12-16µ.

suggests it is not bilateral, and this would help explain why it is such a straight fiber. It is much more time consuming to prepare samples for TEM than SEM, and therefore more expensive. TEM will probably require industry support from ARE, AOBA or TSN.

Statistical Analysis

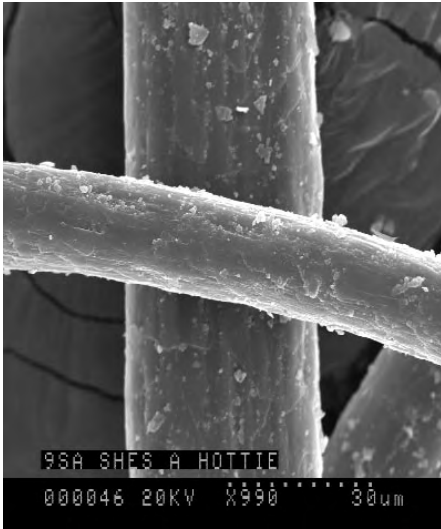
*"7.0 Scale/100 micron seems to be a distinctive parameter for suri."*⁶

Dr. Davitt supplied the author with 1.7 megabyte, 8 bit gray scale, TIFF files captured with a Scion Grabber card from the SEM. Two micrographs were taken of each sample. One to three fibers could be measured in each micrograph. These black and white micrographs had remarkable brightness and contrast. I used the NIH *Image-J* software to measure the diameter of fiber samples, and using the angle tool, the angle of scale perpendicular to the fiber. There was an obvious difference between huacaya and suri samples. Suri samples were typically less than 45 degrees, while huacaya and llama were closer to 70 degrees. Both scale edge angle and MSF can be used to identify suri from huacaya or llama fibers.

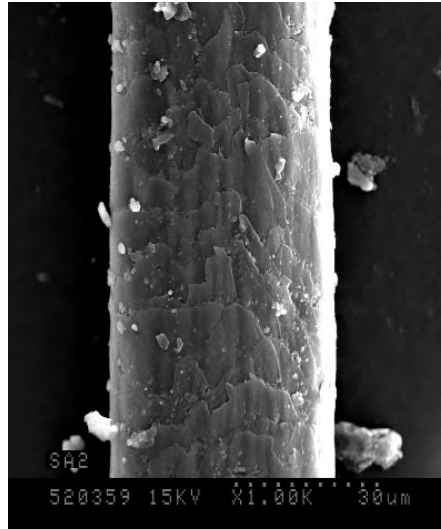
Using modified IWTO-97 methodology, the MSF of our suri samples was 6.15 scales per 100µ. This is about 20% superior to cashmere or the Peruvian suris in Antonini's study. Scales were frequently as long as the fiber was wide. There did not appear to be a relationship between scale length and fiber diameter as reported in the literature for other specialty fibers. This is good news for suri breeders, since selecting for fineness should not adversely affect luster. The average scale length was 16.25µ. Antonini concluded that;

*"7.0 Scale/100 micron seems to be a distinctive parameter for suri."*⁶

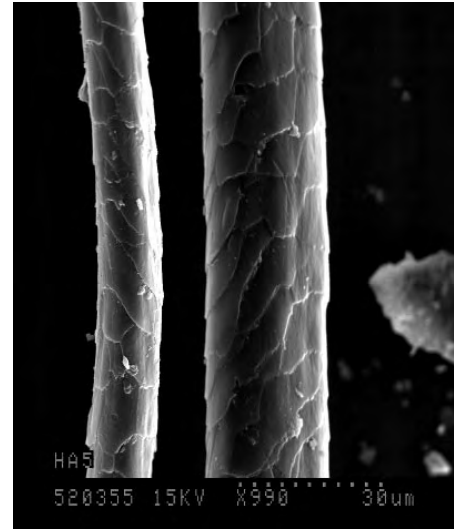
While highly-evolved suris like those I analyzed have an even lower MSF, our data certainly supports that assertion. Separating out the Phase 2 data which was taken from a uniform collection site, the difference between our suris and Antonini's was even more significant.



Suri alpacas do have guard hair. Here we see a 24 μ secondary fiber in front of a 40 μ guard hair.



The number of scales per 100 μ varied depending on where you counted them. Suri guard hair had a MSF of 8.65 with a range of 4-13.



Bright Huacaya – MSF 11. Huacaya fiber had a higher MSF than suri and a 70 degree rather than 45 degree scale edge angle.

- MSF 5.5 2nd & 3rd fleece
- MSF 5.8 virgin fleece
- Range 3-10.25
- MSF guard hair 8.65
- Range 4-12
- Phase 1 & 2 combined MSF 6.15
- Substantially lower than Antonini's Peruvian data (7.5).

MSF should not be dissociated with scale height. When the scale height is impossible to measure, and you have to zoom in on the micrograph to 200% actual size to even visualize a scale edge, you have what is essentially a mono-filament like silk. Several of the suris with a relatively high MSF of 7-8 were so smooth that it still had a very slick, cool handle.

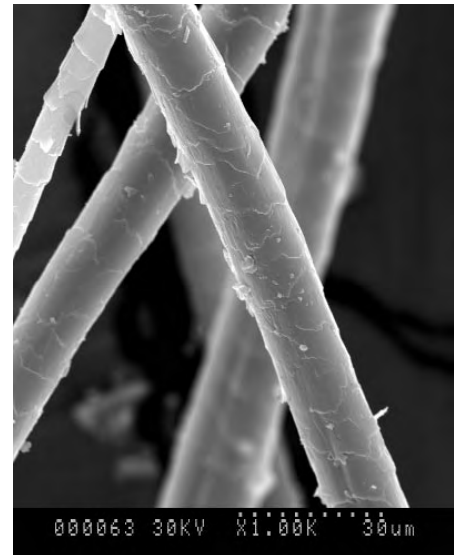
Guard Hair

Primary hair follicles (guard hair) of the Camel Family had a distinctly different scale pattern than the secondary fibers. With the exception of vicuñas, they were usually much stronger (higher AFD) and had an extremely high frequency of scale. These primary fibers had extremely low scale height, and despite their AFD and scale frequency probably had good luster. They were uniformly round, rather than elliptical. The scale pattern had what appeared to be a fractured or very busy “mosaic” appearance. This, combined with their large AFD, made them relatively easy

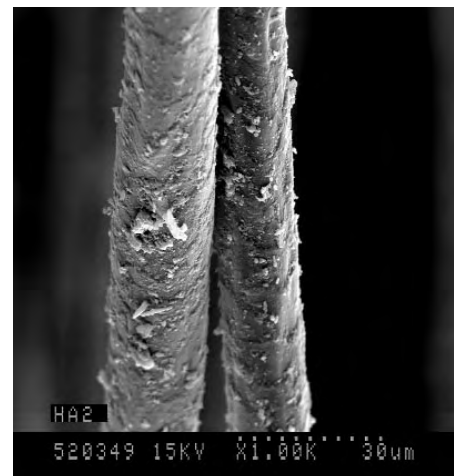
to identify. There was a significant difference between the MSF of guard hair on suris between Phase 1 & 2. This was probably due to the uniform collection site used in Phase 2 and the fact we intentionally included some samples that were “hairy” or had a stronger AFD in Phase 1. It is probably accurate to say that SAC typically have guard hair with about 16 scales/100 μ .

Huacaya

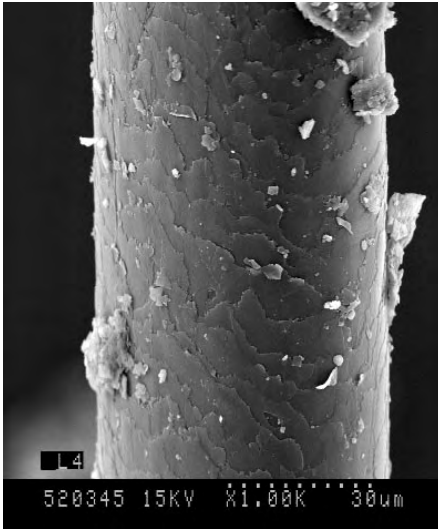
Eight huacayas were evaluated, five males and three females. Samples were collected from virgin fleece. These were highly-evolved huacayas, with 2.0 to 3.0 crimp per cm, clearly defined bundling, and two were unusually bright. AFD was 16-19 micron. While our suri samples were randomly selected, based on fleeces or Yocum-McColl samples we had on hand, these huacayas were hand-picked to represent a dense, bundled, extremely fine, or very bright fleece. Huacaya samples had an MSF of 11.0, which is similar to wool, with a range of 8.0-12.0 MSF. This correlates to an average scale length of 9.0 μ . Scale height was greater than suri, but typically <0.3 μ , which is ten times less than the most highly-evolved merino wool. The scale edge angle of huacaya fibers was about 70 degrees, compared to 45 degrees for suri. This may be responsible for its slightly greater scale height. Among the huacaya sam-



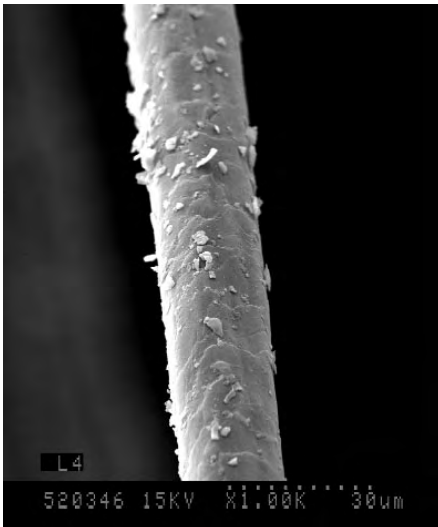
Fine Huacaya – MSF 11.0. Huacaya samples were very fine, seldom exceeding 19 μ .



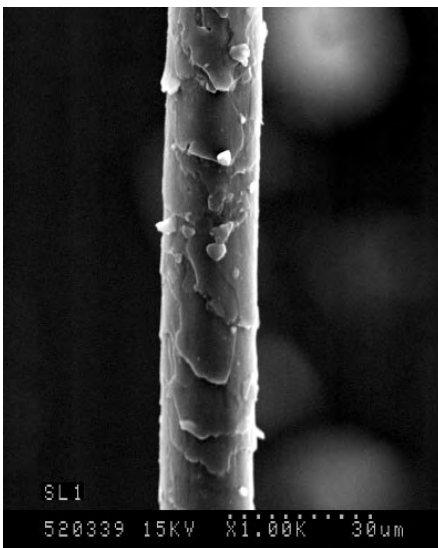
Sheepy Huacaya – MSF 10-12. This is either a 16 μ guard hair or a very “sheepy” secondary from a fine huacaya. Note how similar it is to the undercoat of the double-coat llama (see images on the next page).



Guard hair from a short-wool, double-coat llama had a MSF of 16.5 with a range of 14-19. This sample is 50 micron AFD, which is not unusual.



The undercoat of the double-coat llama is much finer (24 μ) than its guard hair. The undercoat is similar to a "sheepy" huacaya alpaca.



Single-Coat Llama – MSF 8.0. Single-coat llamas had a MSF less than SRS merino wool!

ples, the longest scale length also had the greatest amplitude of crimp. This was a bright, well-bundled, "elite" fleece. Primary and secondary fibers were nearly the same AFD, though the primary fibers could always be identified by their high frequency, and "sheepy" scale pattern.



Llama

There are three distinct breed-types of llama raised in the United States. We tested examples of each, including: a traditional short-wooled, double-coated ccarra llama (32 μ AFD and >50% guard hair); eight single-coat llamas (<9.5% coarse fibers and 21 μ AFD); and 11 SLA-registered suri-llamas, most of which had pedigrees that were several generations long. (They are not hybrid alpaca x llamas).

The surface structure of a ccarra fiber sample looked almost identical to huacaya samples with an MSF of 11.5. However, their primary hair follicles (guard hair) had a much greater AFD, and was routinely >50 micron. Secondary fibers averaged 24 microns and looked very "sheepy." The llamas' guard hair had an MSF of 16.5 with a range of 14-19. The surface structure of a double-coat llama shows a much greater similarity to huacaya fibers than suri. This may be of interest to archaeozoologists, and could have some taxonomic significance.

Secondary fibers of single coat llama were very suri-like with an MSF of 8.0 and a range of 7.5-10.0. These highly-evolved 21 μ llama fleeces are indicative of what is shown in Alpaca and Llama Show Association (ALSA) medium- and long- wool halter classes. Starting from very humble beginnings, it has taken llama breeders 30 years (10 generations) to develop from a double-coat

to a single-coat fleece of this quality. These llamas had a scale height less than or equal to huacaya alpacas. Handle could be either warm or cool.

The suri-llama samples had an MSF of 7.0, which is slightly superior to Antonini's Peruvian suri alpacas. Six of the 11 donors were top ten World Futurity suri-llama champions. Alpaca breeders should take note of how quickly llama breeders have been able to improve fiber characteristics. Huacaya breeders should be able to add brightness to their fleeces relatively quickly using SEM, and suri breeders should be able to simultaneously reduce AFD while increasing luster.

Baby Camel

The two Baby Camel samples (Bactrian camel) were imported from China. They had been de-haired to less than 2% coarse fibers (>30 μ). The Baby Camel was very fine, <18 micron, and had an MSF of just 6.875, with a range of 6.15-8.0. It's resistance to compression felt less than huacaya, but was still very "lofty" compared to suri. It had a warm, rather than cool, handle. The frequency and amplitude of crimp was not visible since all of its fibers had been aligned into a roving. It did not appear to be a particularly bright fleece, yet it had an MSF similar to suri, which had not been washed or de-haired. Plucking a string of fiber out of the camel's roving and wrapping it around our fingers revealed that it was much brighter than our first impression. (This straightens the fibers).

As McGregor found with cashmere, crimp does appear to reduce luster. The warm handle of Baby Camel may also suggest that scale height and crimp are as important as MSF. The scale height of camel did not have an abrupt edge like wool or cashmere, but was measurable with digital imaging tools and was similar to huacaya. Dr. Davitt noted that the specialty fibers like cashmere, silk, SRS merino, and Baby Camel, were definitely more "fly-away" than suri. She even wondered if they would "stay on the SEM stubs when the electron beam hits them!"

- De-haired baby camel
- Low MSF (6.875)
- Higher scale height than suri
- Crimp reduces luster & handle
- Brighter if straightened

Suri breeders should be proud of the fact that a random sampling of Bolivian suri alpacas equals or exceeds the MSF of washed and de-haired Baby Camel.



Guanaco

Dr. William Franklin, one of the world's leading authorities on guanacos and vicuñas, supplied wild-caught guanaco samples from the Falkland (Malvinas) Islands. Four of the samples came from the back near the top line, and one from two males who were biting each others' necks. Four were red-dish-brown to fawn in color and one sample was white, probably coming from high on the side. This was truly a random sampling!

- 5 samples from the Falkland Islands
- MSF 11.0
- 10-60 micron AFD
- Lower MSF than vicuña
- Distinct guard hair with undercoat

Based on the similarity of their incisors, the guanaco is probably closely related to the llama, whereas the vicuña is closely related to the alpaca. The MSF of these authentically-pure guanacos certainly supports a close relationship between the guanaco and the double-coat ccarra-type llama. The undercoat of the guanaco samples was very fine, and some fibers were as small as 10 microns! However, the guard hair was much more prevalent than any of the other breeds or species of SAC, and several 60-micron guard hairs would dominate nearly every micrograph, making it difficult to isolate the much-

finer secondary fibers. It would be interesting to analyze de-haired guanaco roving.

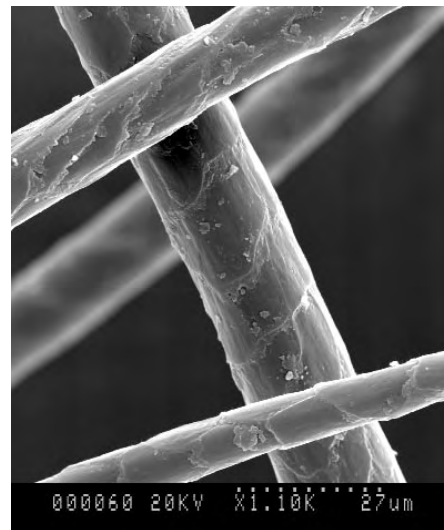


Vicuña

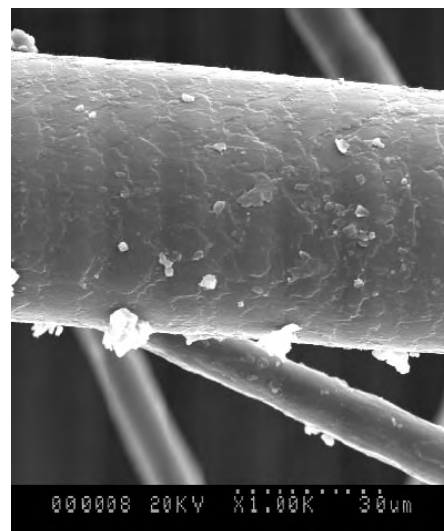
We analyzed three wild and three domestic vicuñas. Dr. Franklin supplied the vicuña samples from the Pampa Galeras National Vicuña Reserve in Peru, and Dr. Toni Cotton the domestic vicuñas from Jack and Miriam Donaldson's farm in Findlay, Ohio. The wild vicuñas were two adults and one cria. Samples were collected from center/middle back, top center neck, and center of back with guard hair intact. The domestic samples were from adult males, and had been de-haired by hand. Staple length was 40-50mm. The providence of captive vicuñas is not as likely to be as pure as wild vicuñas, especially in European zoos where South American exhibits will frequently house all the members of the SAC together. However, these samples had largely similar MSF and AFD.

- 6 samples (3 wild-caught)
- Range 8.5-15 scales/100 microns
- MSF 12.1875
- 12-15µ AFD
- Very uniform

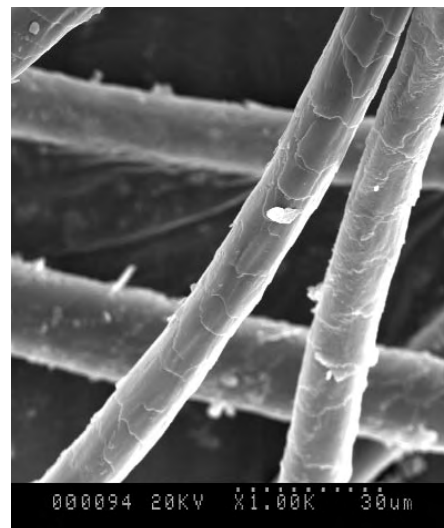
The vicuña samples were among the most interesting of the study. They had a higher MSF than either huacayas or llamas, and the difference between primary and secondary fibers



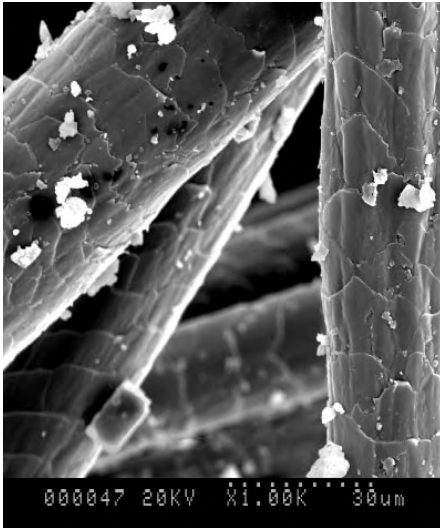
Baby Camel – MSF 6.875. Crimp greatly reduced the luster of this de-haired roving. Straightening the fibers showed its inherent luster.



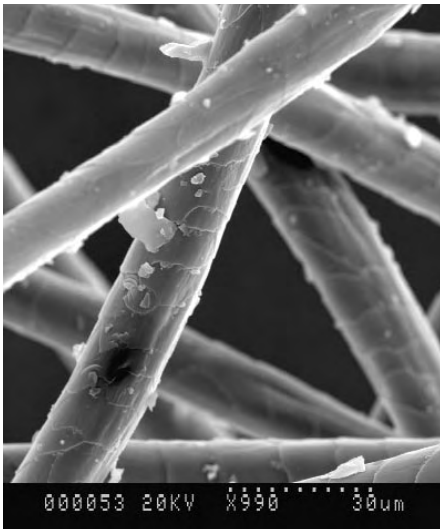
Guanaco fiber was characterized by 60 micron guard hair and very fine undercoat. The guard hair is in front of the 10-12µ undercoat .



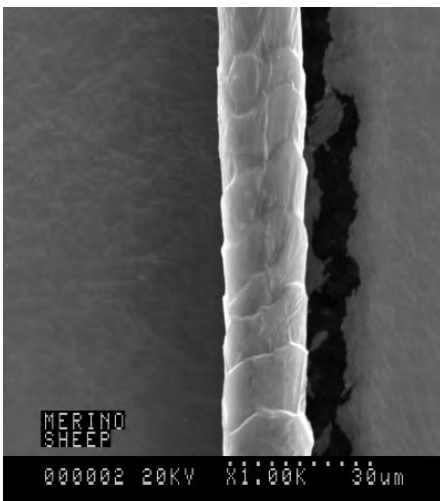
Vicuña – MSF 12.875. The vicuña samples had a higher MSF than llama, guanaco or huacaya. AFD 12-15µ.



Suri x Huacaya Cross – Average MSF 8.4. Three F1 or BC1 suri x huacaya crosses from Australia were analyzed.



Paco-Vicuña – MSF 13.6. Paco-vicuñas had the highest MSF in the study, and a much greater range of AFD than the pure-bred vicuñas.



SRS Merino – MSF 8.6. While half the scale height of other sheep breeds, SRS merino is still more than ten times greater than huacaya or suri alpaca.

was difficult or even impossible to determine by SEM. This may be one reason the MSF was higher, since with all other members of the SAC, it was possible to count primary and secondary fibers separately. This will be amusing to those of you who have ever de-haired a vicuña fleece. (Those little red guard hairs are easy to see but hard to pluck out!) The MSF and AFD of the vicuña samples were the most uniform of all SAC tested. This is a significant observation, considering the random nature of the wild-caught samples. A follow-on analysis of vicuña fiber with SEM should probably analyze guard hair separately from the under-coat.

HYBRIDS: First-Generation Suri x Huacaya Cross

Kenneth Madl of Aviana Farms, supplied three colored suris from his herd which is agisted in Strathbogje, Victoria, Australia. Two were black and one silver-grey, 11 months old. Two were F1 suri's with 2-3 generations of suri x huacaya crosses in their pedigree, and one was a Back Cross 1 with two generations s x h and one s x s. Two of these went on to win their classes at the 2005 Australian national alpaca show. Over 3,200 suri alpacas were imported into the United States from Peru, Bolivia, and Chile between 1991-98. With such a large population to start with, the vast majority of American breeders do not cross huacaya and suri alpacas. Many fewer suris were imported into Australia, and as a result it is a commonly-accepted practice in that country to cover a huacaya female with a suri male.

- Three samples from Australia
- Two true black, one silver-gray
- Range 6.25-11 scales/100µ
- 8.4 MSF (intermediate between huacaya & suri)

As the photos indicate, these alpacas are phenotypically suri and would not be out of place in most colored suri alpaca herds in the United States. While it is a small sample size, the

MSF is intermediate between a huacaya and suri, which may or may not be due to their huacaya ancestry. (The suri with lowest MSF had the greatest percentage of huacaya pedigree). The scale edge and height on 2 of the samples was more distinct than most suris, particularly one of the blacks.

Paco-Vicuña

A paco-vicuña is the offspring of an alpaca and a vicuña. A single paco-vicuña sample was evaluated from the herd of Phil and Chris Switzer in Estes Park, Colorado. Five fibers were analyzed in two micrographs. The providence of this animal could not be verified, but this breeding male had many vicuña-like characteristics, including body size, weight, bi-coloration, staple length, and personality. It was an in-utero offspring out of an imported Chilean huacaya.

- One sample
- Range 11-17 scales/100 microns
- 13.6 MSF
- 13-24 micron AFD
- Higher MSF than huacaya or vicuña

This animal had the highest MSF of the series, which probably goes a long way toward proving its vicuña pedigree. The uniformity of AFD was not nearly as pronounced as a pure vicuña.

OTHER SPECIALTY FIBERS: Soft Rolling Skin (SRS) Merino

As anyone who has ever shopped for an expensive man's suit can tell you, ultra-fine merino wool should probably be classified as a "specialty" fiber. Even an untrained hand can distinguish the difference between a 16µ wool and more common fabric. When merino is blended with cashmere or suri, the handle improves even more. The two SRS merino samples we tested had a MSF of 8.6, which is exceptional for wool. These two- and three-year-old merino rams had a scale height of just 3-4 microns, half that of most sheep breeds. However, the abrupt scale edge was easily measured. These were remarkably well-bundled fleeces, with each lock measuring less than ½ cm



SRS Merino Fleece

with 6-7 crimps per cm. (This is two to three times the curvature of a typical huacaya). The two samples were provided by Ian Watt of Moro Bay, California.

Cashmere

SEM has demonstrated that suri fiber is most similar to cashmere and mohair. These goat fleeces must be de-haired, but have an MSF and surface structure that is much more similar to suri than huacaya or wool. While huacaya breeders can learn much from research based on merino wool, suri breeders should probably look to other resources.

Two cashmere samples were analyzed. One sample was collected in the grease from a domestically raised doe. She had an MSF of 7.6, scale height of 1-2 μ , and 17 μ AFD. We also tested a washed and de-haired cashmere sample which was imported from China and supplied to us by Angus McColl. Mr. McColl said that white Chinese cashmere was finer than other colors. It was very fine, at 14.2 μ AFD. Since it had been washed, it was also very bright, but had an MSF of only 8.625, about like SRS merino. Its range was 7-10 scales per 100 microns, and both samples were within the range of AFD and MSF reported in a literature search for cashmere.^{3, 7, & 8}

Over five-thousand metric tons of cashmere are sold each year, compared to just 550 tons of suri. By verifying the low MSF and scale height of suri

with SEM, the alpaca industry should be able to substitute suri fiber for many applications that currently use cashmere or mohair.



Mohair Fleece

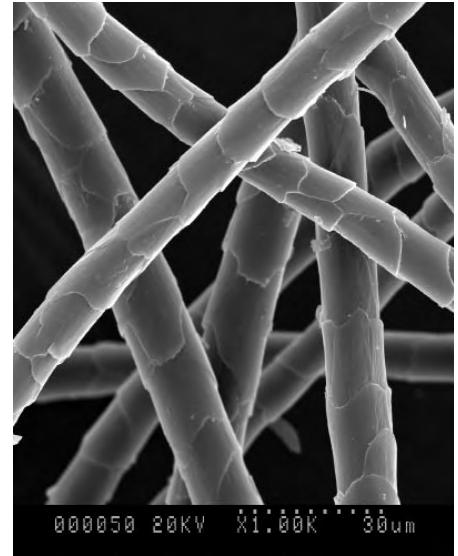
Mohair

We evaluated a single sample of imported fawn mohair. Most mohair production comes from South Africa. Mohair is brighter than cashmere, and subjectively, appears to be as bright as suri. This sample had been washed. Even though mohair is very coarse (typically <math><32\mu</math>), it still had a lower MSF than suri. This is largely offset by its much greater AFD and more distinct scale edge. Goat fleeces must be de-haired, but are microscopically more similar to suri than wool. Seven-thousand tons of mohair are sold each year, indicating the great potential that suri fiber does have. Suri alpaca can certainly be marketed as having similar luster to mohair, while being much finer.

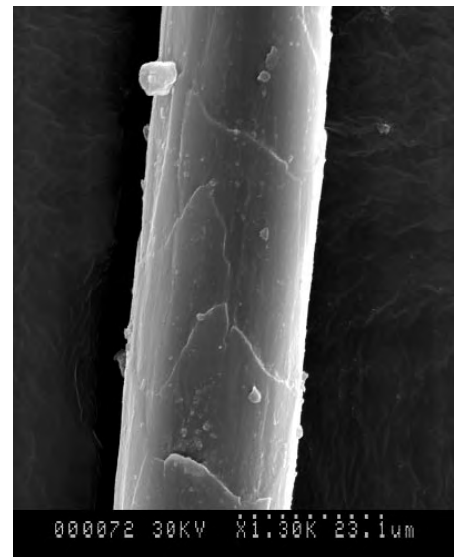
- One sample
- South African mohair
- Mohair is from a goat like cashmere
- High luster
- MSF 4.25
- Distinct scale compared to suri
- 32 microns (coarse)

Angora Rabbit

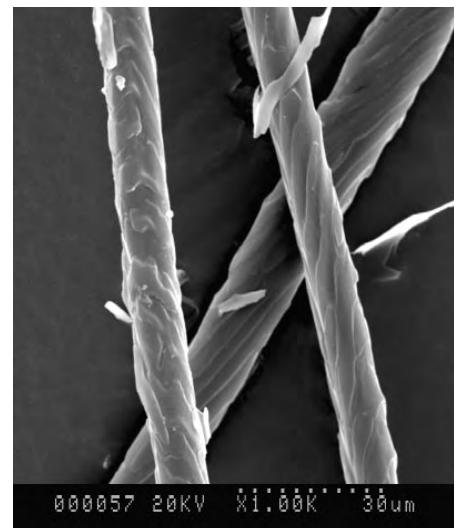
Angora is a single-coat fiber that does not need to be de-haired. Suri breeder Kathleen Cullen gave me a sample of white Angora from her flock of German rabbits. White Angoras are large-bodied and suitable for harvesting their fiber. The cuticle scale pattern of Angora was unlike any other fiber sample. It can best be described as an "other-worldly" spiral pattern.



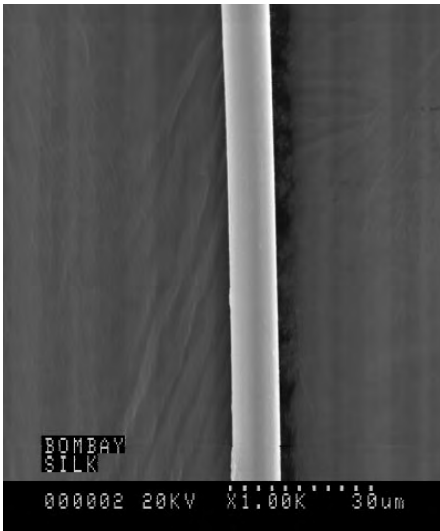
White Chinese cashmere, MSF 8.625, 14.2 μ AFD.



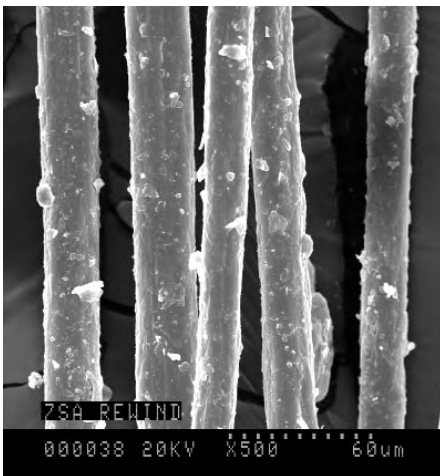
Mohair – MSF 4.25, AFD 32 μ . Mohair is bright but coarse.



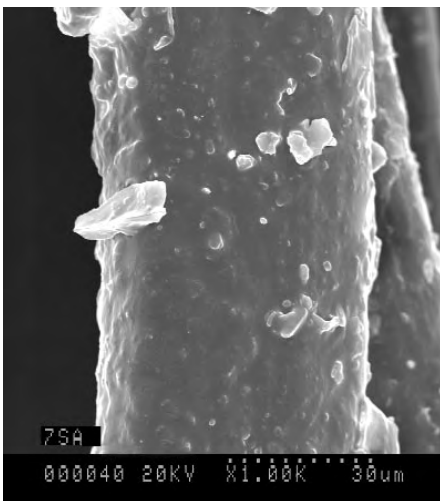
Angora rabbit – MSF 10.6. Angora is a single coat fleece that does not need to be de-haired. It has an unusual "spiral" scale pattern.



Bombay Silk – AFD 10-12 μ . Silk does not have a cuticle scale since it is reeled together from 4-20 filament ends from the silk worm.



IWTO methodology views fiber samples at 600 X magnification which allows 5-6 fibers to be analyzed at a time. Dr. Davitt increased magnification to 1,000 X so suri scales could be visualized more easily.



MSF was not related to AFD as it appears to be with other specialty fibers. This is good news since it suggests you can select for enhanced luster and reduced AFD simultaneously.

- Single coat fleece
- 11-15 micron AFD
- Spiral scale pattern
- Range 10-12 scale/100 microns
- 10.6 MSF

Angora is so fine and without guard hair that we could easily measure three fibers per micrograph. The deep grooves between the spiral-shaped scales probably reduce the handle of Angora in the same way that an abrupt scale edge effects wool. The scale edge angle is similar or greater than huacaya.

Bombay Silk

Imported Bombay silk had an AFD of 10-12 micron. “Bombay” silk comes from the mulberry leaf eating silk worm. One-hundred-ten-thousand tons of silk are sold each year, making it the dominant luxury fabric in the world. Since it is not a mammal, silk does not have a cuticle scale structure. Silk is reeled together from 4-20 individual filament ends to make a single monofilament that adheres together due to the gummy texture on the surface of the filament. Silk is washed in warm water to separate the filament

from the silk worm’s cocoon, and again after it is wound. It was very bright. Even at 1,000 X, it was not possible to see where the filaments had been reeled together. It appears that silk is the only natural fiber which has a smoother surface structure than suri.

Challenges and Recommendations

SEM of suri fiber is a fortuitous convergence of research and marketing.

Suri alpacas have a lower MSF and much lower scale height than cashmere, but no one knows it! To secure their place as the natural fiber with the greatest combination of fineness and luster, AOBA judging standards need to prize luster as highly as an independent lock structure. And we believe this needs to occur in the show ring, not just on the score card for a fleece competition. Additionally, we recommend that the Alpaca Research Foundation (ARF) help sponsor research on suri fiber. (The Suri Network already is). Clearly, AOBA and the Alpaca Fiber Cooperative of North America (AFCNA) both need to make suris’ unique characteristics an integral part

Acknowledgements

The authors would like to thank the following friends and colleagues for their assistance:

- Dr. William Franklin, who supplied us with wild-caught guanaco and vicuña samples from Pampa Galeras and the Falkland Islands.
- Dr. Toni Cotton of Findlay, Ohio, who provided the domestic vicuña samples.
- April and Richard Angotti of Benvenuti Farms in Bend, Oregon, who provided the highly-evolved huacaya samples.
- Sherry Sheridan of Aloha Farms in Bend, Oregon, who provided the double-coat llama sample.
- Susan Tellez for her foreign language literature search of SEM of the SAC.
- Kenneth Madl, who provided us with many publications on contemporary wool and cashmere research from Australia, and his first-generation suris from suri x huacaya crosses.
- Ian Watt, for help in identifying round versus elliptical fibers, and for providing the highly-evolved SRS merino samples.
- Our local wool guild, the Textilians, who provided us with cashmere, silk, and Baby Camel (Bactrian camel) samples.
- Angus McColl, who provided the white Chinese cashmere.
- Dr. Kathleen Cullen of Spokane, Washington, who provided the white Angora.
- Chris and Phil Switzer of Estes Park, Colorado who supplied the paco-vicuña sample.
- Dr. Chris Davitt, WADDL, who prepared and scanned the fiber samples and tutored me on the use of imaging software.

of their marketing and advertising campaigns. The low scale height of huacaya fiber compared to wool can also be emphasized! To be competitive in the luxury fiber market, suri breeders need to reduce the AFD of their clip.

Fortunately, there was no correlation between luster and AFD in either this or Antonini's study, and it should be possible to select for both characteristics simultaneously.

Cheryl and I have been raising alternative livestock for over thirty years. As a result we usually take a macro view of the issues which face our industry. We have learned that if you do not breed for something, you lose it. Whether this is maternal ability (milk production), thriftiness, conformation, or luster, if you take a characteristic for granted, you will lose it. The results of this research are both exciting and sobering. For instance, there is certainly no reason not to show shorn suris in AOBA halter classes, due to the close correlation between a virgin, 2nd, and 3rd fleeces MSF. On the other hand, we are probably not using some of our best males, those with the greatest luster and lowest MSF.

Summary

It would be premature to assign value to one lock type over another until a more thorough SEM study is made of suri alpaca fiber. Like many scientific enquiries, this one has raised as many questions as it has answered. The authors have scanned enough fiber samples to determine that suri alpaca fiber is measurably different in scale length, frequency, edge height, and edge angle from wool and huacaya fiber. It is probably most similar to cashmere and mohair but with an even lower scale height. The "take home" lesson from this SEM study is that what is truly unique about suri alpaca fiber is its luster. This should be kept foremost in mind in any future discussion of possible breed standards, end-use, or show standards.

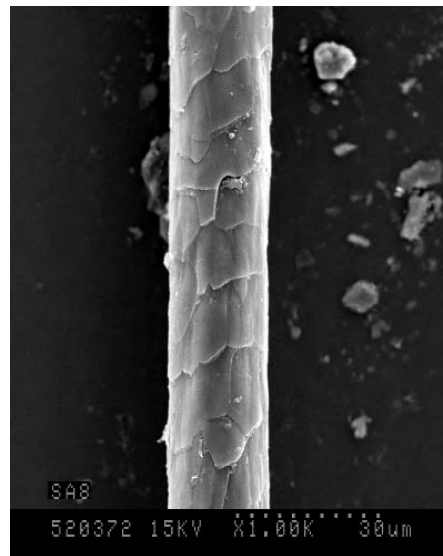
- Suri and huacaya fleece can be differentiated by SEM

- The "long smooth scale"TM of suri fiber averages 16.3 μ long
- Huacaya samples averaged 9.0 μ
- This equates to a MSF of 6.125/100 μ suri and 11.0 MSF/100 μ huacaya
- MSF was not correlated to fiber diameter.
- A low MSF was not correlated to a twisted lock and may be inversely related
- Scale height on both huacaya and suri is much less than previously reported.

Andy and Dr. Cheryl Tillman funded this research on suri alpaca fiber. The Tillmans imported the influential colored suri alpacas from Hacienda Acero Marka near La Paz, Bolivia in 1996. Andy has raised llamas since 1975 and alpacas since 1982. He is a member of The Suri Network research committee. Cheryl Tillman has been a camelid veterinarian since 1985. She sits on the board of directors for the US Animal Health Association, serves on the AOBA/ARI Government & Industry Relationship committee, and has reviewed research proposals for Morris Animal Foundation for many years. They can be contacted at andy@tillmansranch.com.



It would be premature to assign value to one lock type over another until a more thorough study of SEM is made of suri alpaca fiber.



A fan-shaped lock and narrow flat lock may be under-appreciated for luster.

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